International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 8, Issue 2, Apr 2018, 591-600

NUMERICAL ANALYSIS OF RUBBER ASSISTED SHEET HYDRO-FORMING PROCESS AND ITS EXPERIMENTAL VERIFICATION

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ABSTRACT

Rubber assisted sheet hydro forming process is an upcoming technology, which improves the quality of finished product. The final formed products obtained from process are free from wrinkling. This process is similar to hydro-forming process. In this process, thin rubber pad is used to separate the blank (sheet metal) from the pressurized liquid media. The aim of the present work is to model the rubber assisted sheet hydro-forming process using finite element method and to validate the numerical model by carrying out experiment. The finite element model of this process has been developed in ABAQUS/Explicit finite element software. Non-linear material properties for both rubber and blank have been considered in the analysis. The effects of punch cone angles on the sheet thickness variation have been studied. Also, the variation of von-Mises stress has been studied for different cup cone angles.

KEYWORDS: Sheet Metal Forming; FEM; Hydroforming Process; Rubber pad Forming & Cone Angle

Received: Jan 27, 2018; **Accepted**: Feb 17, 2018; **Published**: Mar 12, 2018; **Paper Id.**: IJMPERDAPR201869

Original Article

INTRODUCTION

Deep drawing process is used to transform a flat sheet into a cylindrical, cup/ conical or box shaped parts. In deep drawing process, a punch is used to apply pressure on sheet metal against a die, so that material flows between the surfaces of punch and die. With this process, complex axi-symmetric parts can be made using minimal operations and generating minimal scrap. There can be a number of defects in the parts drawn using conventional deep drawing process. Some of the most common defects are wrinkling (either in flange or wall region), tearing, earing and scratches in surfaces [1]. In contrast to conventional deep drawing process, in sheet hydro-forming deep drawing process, a bed of pressurized viscous fluid is kept at the bottom of the sheet. This fluid supports the sheet during the forming process [2, 3]. Colgan et.al [4] studied the effects of different parameters influencing the deep drawing process using design of experiment and statistical analysis. It was observed that there is negligible change in thickness with the variation of blank holder force, type of lubrication used. Reddy et al [5, 6] investigated on the process parametric and geometric effects on the conventional deep drawing process and concluded that the thickness variation and punch force is affected by the process parameters. Joachim Danckert [7] investigated the modified hydro-mechanical deep drawing process, wherein it was assumed that pressure on the flange (at flange-die interface) is uniform throughout deep drawing process. Swadesh et.al [8] studied the effect of the pre-bulging pressure and the cutoff pressure on thickness distribution and surface finish in

hydro-mechanical deep drawing process. Hama et.al [9] studied the hydro-forming deep drawing for conical cup for perfect forming, which cannot be drawn by conventional deep drawing method.

Although a great deal of works have been done to studied on the sheet forming process for cylindrical cup shapes for different materials, very few works has been done on conical cups made of copper. In the present work, studies have been made to form conical cups of varying cone angle.

MATERIALS AND METHODS

The characterization of material is very important for the simulation of sheet metal hydroforming process, as the material physical properties are the inputs for Finite element simulation. In the present study, the blank is made of pure copper and natural rubber sheet is used to separate blank from the fluid. Tensile testing of the copper and rubber sheet samples has been carried out in Universal testing Machine (UTM).

Material Properties for Pure Copper Sheet

The tensile test specimen for pure copper, in annealed condition, is shown in figure 1. The test has been carried out as per ASTM E8/M standard. The engineering stress-strain diagram for pure copper sheet is shown in figure 2. The material properties for pure copper sheet are shown in Table 1.

Figure 1: Tensile Test Specimen for Pure Copper

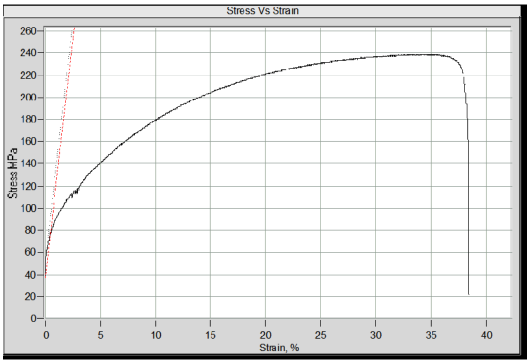


Figure 2: Stress-Strain Diagram of Copper Sheet

Table 1: Material Properties for Pure Copper Sheet

Property	Value
Yield Stress (Y)	78 N/mm2
Ultimate Tensile Strength (UTS)	239 N/mm2
Strain Hardening Component (n)	0.44
Strength Coefficient (K)	470
Density	8.96 E 9 kg/mm3
Young’s Modulus	117 GPa
Poisson’s Ratio	0.33

Material Properties for Natural Rubber Sheet

The stress-strain diagram for rubber sheet is shown in figure 3. The material properties for rubber sheet are shown in Table 2.

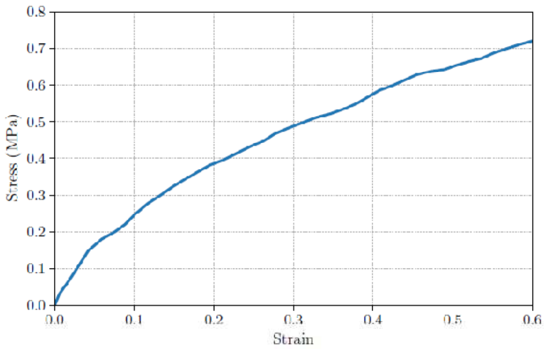


Figure 3: Stress-Strain diagram for Natural Rubber

Table 2: Material Properties for Natural Rubber

Property	Value
Size	Φ 100x4 mm
Density	910 E 9 kg/mm3
Young's Modulus	0.001 GPa
Poisson's Ratio	0.4997

Geometric Details

The conventional sheet hydro-forming assembly is shown in figure 4. The rubber assisted sheet hydro-forming is shown in figure 5. The geometric details of four different punches are shown in figures 6. The analysis has been done for four different conical punches having different cone angle.

- Punch with cone angle - 110o
- Punch with cone angle - 95o
- Punch with cone angle - 84o
- Punch with cone angle - 64o

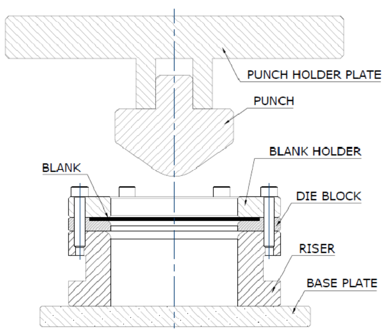


Figure 4: Conventional Sheet Forming Set-up

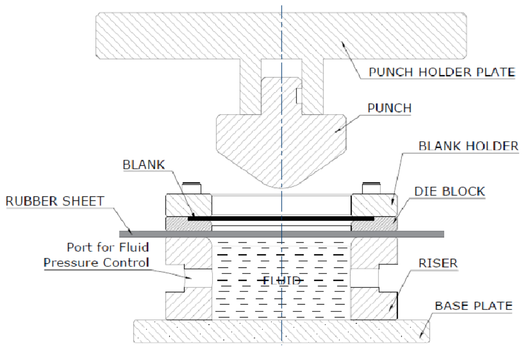


Figure 5: Rubber Assisted Sheet Hydroforming Set-up

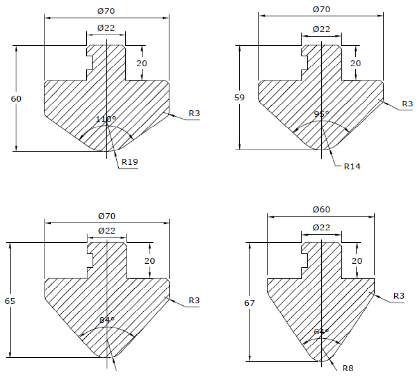


Figure 6: Geometrical Details of the Punches

Finite Element Model

Finite element analysis for the simulation of sheet hydro-forming process has been carried out in general purpose finite element code ABAQUS-explicit. The simulation has been carried out for both conventional and rubber assisted hydro-forming process. The finite element theory and finite element modeling methods along with element descriptions used for simulating sheet metal forming in ABAQUS are shown in Abaqus manual [10]. The FE models are shown in figure. 7. The blank has been idealized as shell. The blank has been meshed with conventional shell element 'S4R'. The element S4R is described by 4-node, quadrilateral stress/ displacement shell element with reduced integration and is with large-strain formulation. As the tool components are assumed to be rigid during the forming operation, therefore rigid element 'R3D4' has been used for there discretization. Element R3D4 is a 3-d, 4-node bilinear quadrilateral rigid element. The mesh details for the assembly are shown in Table 3. The die, die block and holder have assumed to be rigid and have been completely constrained. Except axial direction, punches have been constrained in other directions. The punches have been given velocity of 200 mm/min in axial direction. The loads and boundary conditions are shown in figure 8. Coulomb's friction model has been used for simulating the sliding friction between different contact pairs. The coefficient of friction between blank and punch contact pair is 0.15. Also, the coefficient of friction between blank and blank holder is also assumed to be 0.15.

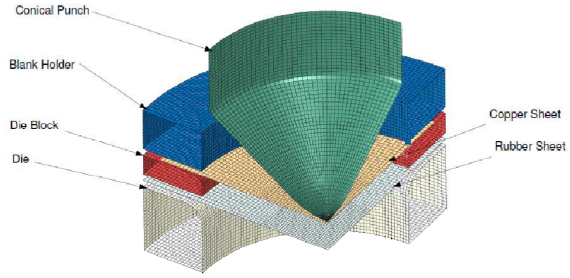


Figure 7: Finite Element Model of Rubber Assisted Deep Drawing Setup

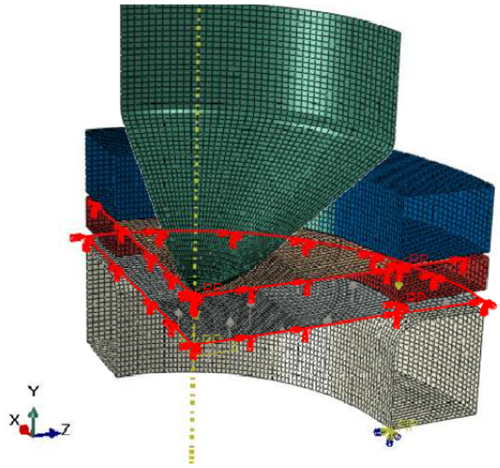


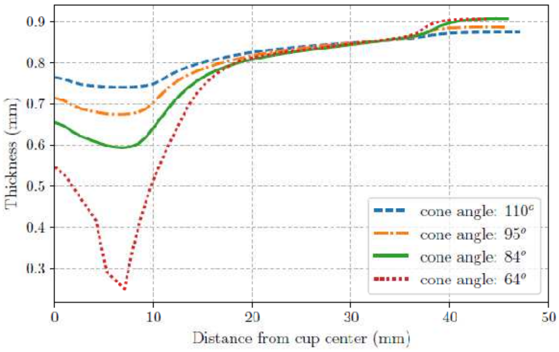
Figure 8: Loads and Boundary Conditions Used in the Present Study

RESULTS AND DISCUSSIONS

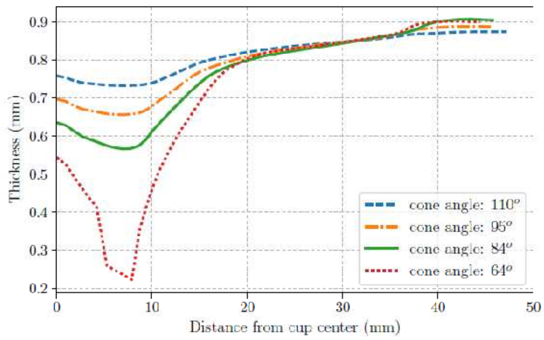
The numerical results are evaluated for conventional, rubber assisted and rubber assisted hydro-forming process using the finite element technique for making conical cup shape. The blank material used for the numerical simulation is pure copper sheet of 0.9 mm thickness. The variation of thickness along the cup wall with cone angle has been studied for the different forming processes mentioned above. The variation of Von-Mises stress has also been studied.

Thickness Variation Along the Cup Wall for Different Forming Processes

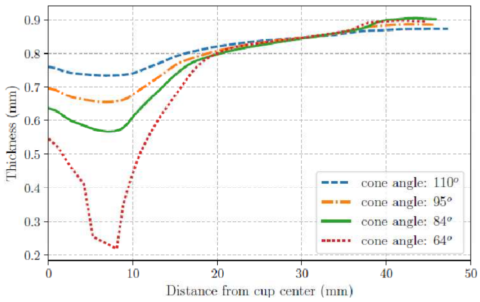
For the conventional forming process, the thickness variation along the cup wall with varying cone angle is shown in figure 9a. It can be observed from the graph that with the increase in the cone angle the thickness near to center of the cone decrease, and after a critical cone angle sheet fractures. Also, there is an increase in thickness built-up, near to holder region, with the decrease in cone angle. The thickness variation along the cup wall with varying cone angle for rubber assisted sheet forming process is shown in figure 9b. Similar to conventional process, in this case, thickness decreases with the decrease in cone angle. Thickness build-up near the holder region increases initially with the decrease in cone angle, but at lower cone angles the thickness built-up does not change. As shown in plot, for the cone angle of 64o, the thickness variation near to center is not continuous. This is due to large plastic deformation causing fracture in this region. The thickness variation along the cup wall with varying cone angle for rubber assisted sheet hydroforming process is shown in figure 9c. The thickness variation for this case is very similar to rubber assisted forming process. In this case also, at smaller cone angle fracture near to center of the cup occurs. This is evident with the large thickness variation at the cup central region.



A). Conventional Forming



B). Rubber Assisted Forming



C). Rubber Assisted Hydroforming

Figure 9: Variation of Thickness Along Cup Wall for Different Cone Angle

Effect of Cone Angle on Von-Mises Stress Distribution in Conical Cup

The von-Mises stress distribution for different cone angles corresponding to conventional, rubber assisted and rubber assisted hydro-forming process are shown in figure 10, figure 11 and figure 12, respectively. In all the forming process mentioned above, the von-Mises stress in the formed cup increases with the decrease in cone angle. With the decrease in cone angle, the maximum von-Mises stress location shifts towards the center region. In comparison to conventional forming process, the von-Mises stress in the cup is more in rubber assisted forming/ hydro-forming process. The difference in maximum von-Mises stress in rubber assisted forming process and rubber assisted hydro-forming process is less. The high von-Mises stresses in the cup central region corresponding to 64^o cone angle shows fracture in the cup. In the rubber assisted hydro-forming process, the spread of maximum stresses is localized as compared to rubber assisted forming process.

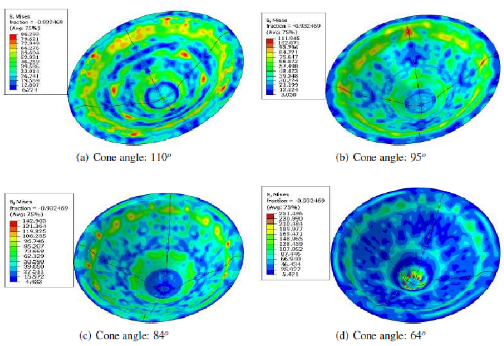


Figure 10: Variation of Von-Mises Stresses in Conventional Forming with Different Cup Cone Angle

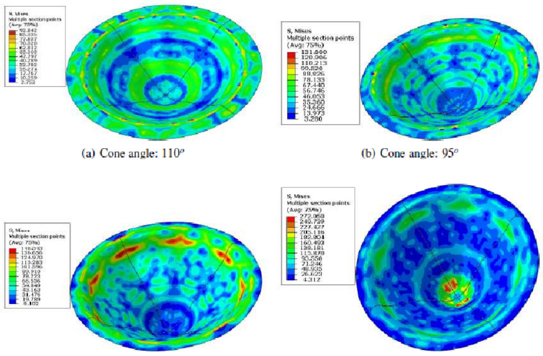


Figure 11: Variation of Von-Mises Stresses in Rubber Assisted Forming with Different Cup Cone Angle

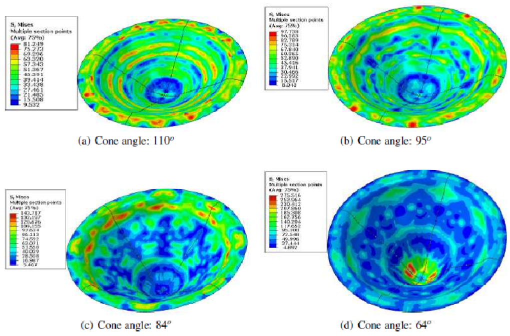
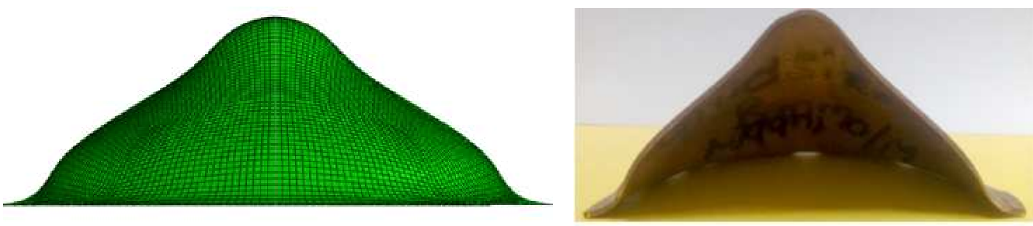


Figure 12: Variation of Von-Mises Stresses in Rubber Assisted Hydroforming with Different Cup Cone Angle

Validation of the Model

The finite element model has been validated for conventional sheet hydro-forming process. The thickness variation and deformed shape as obtained from the finite element analysis have been compared with that obtained from sheet hydro-forming experiment. The FE model has been validated for copper blank with conical die of 84°. It can be observed from the figure 13, that there is a good match between the deformed cups obtained from FE simulation with that obtained experimentally. Also, there is a good correlation between the experimentally obtained thickness variations along the cup wall with that obtained with FE model and is shown in figure 14.



a) Simulated Cup **b) Experimental Cup**

Figure 13: Model Validation: Deformed Shape

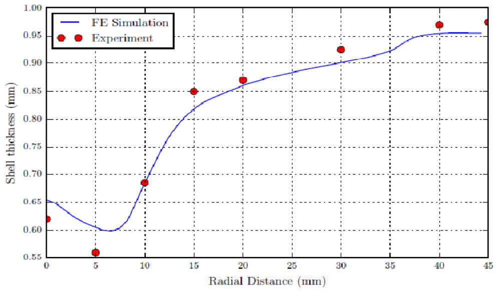


Figure 14: Comparison of Numerical and Experimental Shell Thickness

CONCLUSIONS

In the present work, endeavor has been made to simulate sheet forming processes employing explicit finite element technique. Both conventional and rubber assisted forming processes have been simulated. The numerical results have been evaluated for conical cups made of thin copper sheet. The finite element model has been evaluated using experiment. Good correlations have been observed. The thickness variations along the cup wall have been studied varying cup cone angle. The effects of cone angle on the von-Mises stress and maximum principal stress distribution have also been evaluated.

The following main conclusions are drawn from the study:

- For forming cup with smaller cone angle, the sheet process should be done in number of stages, so as to get the final product without fracture.
- For the same punch velocity, higher percentage thickness reduction is achieved in rubber assisted forming processes as compared to conventional forming process.
- The thickness along the cup wall decreases with the increase in cone angle for all the forming processes studied.
- The thickness build-up near the holder region is small for rubber assisted forming process as compared to conventional forming process.
- The von-Mises stress increases with the decrease in cone angle causing failure at the higher cone angles.

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